Consortium for Oceanographic Research and Education

Introduction

The following CORE Position Paper "A National Initiative to Observe the Oceans: A CORE Perspective" was submitted to Dr. Robert Frosch, Chair of the Ocean Research Advisory Panel's Integrated Ocean Observation Task Team. This paper is intended to complement and expand upon the May, 1999 report submitted to Congress by the National Ocean Research Leadership Council (NORLC). The NORLC report has the strong support of the CORE oceanographic research institutions and is a vital step in the development of an observation initiative. In conjunction with the NORLC report, it is our hope that the CORE position paper will serve as a useful foundation for Task Team discussion and development of implementation strategies to eventually field an integrated observing system.

The overall intent of this position paper is not to advocate a particular balance or direction amongst scientific disciplines or programs. Instead, the paper strives to describe a potential balanced, integrated, long-term observing strategy for the oceans, including the need for system integration studies, pilot projects, and an end-to-end data assimilation and modeling capability. As one of many documents currently being circulated regarding an integrated observing strategy for the oceans and climate, its primary goal is to move the debate from a discussion about requirements to a strategy for how to get started. The paper also includes an enhanced discussion of potential funding and management options for implementation.

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A National Initiative to Observe the Oceans: A CORE Perspective

"Oceans are critical--not just to our economy, not just to our food supply, not just to America's trade and security--but to the fabric of life itself." - Vice President Al Gore

"We've made the investment needed to venture into the skies, and it has paid off mightily. We've neglected the oceans, and it has cost us dearly. This is the time to do for [the oceans in] the 21st century what our predecessors did for space." - Sylvia Earle

"How inappropriate to call this planet Earth when clearly it is Ocean" - Arthur C. Clarke

"Ocean science can no longer be viewed as an esoteric, "off-shore" discipline. It is mainland and mainstream. The health and bounty of our oceans are issues of planetary survival. Nineteen hundred years ago, Seneca predicted that many years in the future "the Ocean will loose the chains of things." Today we are unlocking the very essence of those words with the tools and equipment of unrivaled sophistication. The biocomplexity of the Earth's major systems are the very "chains of things." - Rita R. Colwell

Abstract

"A National Initiative to Observe the Oceans" is a CORE-endorsed white paper describing a balanced, science-based implementation strategy for integrating a system of long-term, interdisciplinary ocean observations. The paper examines existing and proposed oceanographic observing systems that are example candidates for integration, and concludes that integration of such efforts could start immediately. The paper then identifies five interdisciplinary starting points from which an integrated ocean observing system could evolve, and recommends that the federal government and the national ocean community work hand-in-hand to create a set of cooperative and reciprocal relationships to sustain the development of an integrated ocean observing system

Finally, CORE recommends four FY 2001 budget augmentations aimed directly at improving the integration of present efforts: 1) detailed system engineering and design studies to determine whether and how present and planned ocean-observing

systems might be cost-effectively integrated into a more comprehensive system, 2) pilot projects that demonstrate an integrated approach to ocean observations, 3) technology development projects specifically focused on lowering the costs of existing instruments and platforms, integrating different observing capabilities, and developing new sensors and observing platforms for future systems, and 4) projects and/or systems integrating current data resources, synthesize data collection from several sources, and facilitate the use of data in numerical and other models.

A National Initiative to Observe the Oceans

Table of Contents

1: The need for an integrated ocean observing strategy

Why Study the Oceans?

Water covers nearly three-quarters of the Earth's surface, and our planet, seen from space, is blue. The vast oceans circulate the energy and water that control our climate and weather. The oceans are the fundamental source of water vapor in the atmosphere; without the greenhouse effect of atmospheric water vapor, the planet would be frozen like Mars. Nearly all volcanoes and earthquake faults lie under the oceans. Life most likely started in the oceans, and previously unknown forms of life have been found at hot volcanic vents on the sea floor, and at least 99 % of the microbial life in the oceans is unknown. Indeed, biodiversity within the oceans surpasses that of any other Earth system. Ocean organisms are a source of useful chemicals and pharmaceuticals. Changes in marine ecosystems, such as increases in toxic algal blooms, threaten their productivity. Seafood-borne diseases threaten public health. Oceanic life and sediments formed by ocean life help regulate the concentration of atmospheric carbon dioxide, an important greenhouse gas, and act to slow its rapid accumulation in the atmosphere.

For a long time, Americans have understood that sea power is a vital part of national security. Most of America's international trade is transported across the high seas. Storms and tsunamis shape our weather and our coastlines. More than half of us choose to live near where the ocean meets the land. Our fertile coastal zones provide food, recreation, and natural resources for all Americans. A major fraction of the fish harvested from the sea come from highly productive shelf and estuarine waters. The outer continental shelf is the site of major oil and gas exploration, and nearly all of our new reserves of fossil fuels will be found beneath the ocean floor.

A New Sense of Urgency for Increasing Our Understanding of the Oceans

Once it was thought that the oceans were so vast that they and their ecosystems could absorb the impacts of human activities without significant change. People no longer think this way. The oceans cannot absorb all the additional carbon dioxide produced by fossil fuel burning, and the atmospheric concentration of this greenhouse gas has been increasing since the beginning of the industrial age. Indeed, the world has been warming over this period, and particularly in the last two decades; 1998 was the warmest on record.

There are increasing concerns about the biological health of the oceans. Bellwether marine ecosystems, such as coral atolls, kelp forests, and estuaries are threatened. Important fisheries around the world are in decline, and many scientists believe that marine biodiversity overall is in serious decline. This is most unfortunate when one remembers that the oceans are thought to harbor a biocomplexity unrivaled in any other Earth system.

Humans come into closest contact with the ocean in the coastal region. The near-shore region is particularly affected by the consequences of intense human use: point and non-point source water and air pollution, habitat degradation and loss, hypoxia, harmful algal blooms, and overfishing. As much as 85% of US sandy shorelines are eroding due to a combination of factors including sea level rise, river damming, and storms. As the human population along our coasts increases, the net economic risk due to natural hazards, from hurricanes to tsunami-generating earthquakes, naturally increases. Changing climate and rising sea level may further stress the coastal environment.

The changing world situation has shifted the Navy's emphasis from global conflict to regional conflict. The Navy must now operate in coastal zones where the complex interactions between bathymetry , ocean and atmosphere, and biological and human factors influence weapons and sensor systems more directly than in the open ocean environment. The observational basis for understanding these interactions exists in only a few regions. Today's Navy is also environmentally friendly - ships and operations have been directed to minimize their impact on the ocean environment. For example, sea surface temperatures and krill concentrations are monitored to define areas of potential marine mammal activity where ship operations are not permitted. Thus, comprehensive ocean observations can serve national and environmental security together.

Dealing with environmental change will be increasingly critical to the nation in the next century. We will need to disentangle human-induced and naturally caused environmental changes, so we can know whether, when, where, and how to respond. We will need to articulate the temporal and spatial scales of environmental change. The overlapping impacts of global climate change and local pollution on regional ecosystems provide an illustrative example. In short, we will not be able to manage our environment without correctly attributing cause and effect relations.

We are confident that science and technology will rise to the challenge. Already, the examples of El Nino forecasting and stratospheric ozone depletion give us some confidence. An accurate scientific diagnosis of the oncoming El Nino of 1998 promoted the consensus necessary for local and national agencies and governments to undertake disaster preparedness and amelioration steps, and for private enterprise to plan rationally for provision of commodities. A similarly accurate scientific diagnosis of stratospheric ozone depletion promoted the consensus necessary for the nations signing the Montreal Protocols to take remedial action, which is now showing signs of success.

A new approach to Earth and ocean science is needed

Earth scientists of the 21st Century will work to understand the Earth as a system. This will require not only a description and understanding of its subsystems in isolation, the primary scientific goal up to this time, but also of the coupling between them. The interactions among the basic processes are so complex that their neglect in investigative methodology may cause us to miss the most important phenomena. Thus, we need to develop an integrated understanding of the physical, biological, chemical and geological processes governing the entire Earth system. Starting with what we know of its individual components, we must learn how they interact on different time and space scales, and from this understand the new forms of behavior open to the complex system.

It was once thought that the Earth changed significantly only on "geological" time scales, but we are now concerned with its changes on the human time scale as well. In the words of the National Research Council, " if we believed the Earth was a constant system in which the atmosphere, biosphere, oceans, and lithosphere were unconnected parts, then the traditional scientific fields that study these areas could all proceed at their own pace.however,the Earth [is] changing even as we seek to understand it". Because one observational campaign cannot suffice to fix our knowledge, we must commit to observing the system over and over again.

For reasons of intellectual simplicity, as well as of logistical convenience, Earth scientists frequently separate their studies of local, regional, and global phenomena. Now this approach is reaching the limits of its usefulness in many areas. For example, numerical models of the coastal oceans depend upon models of the open oceans for boundary conditions. The same issue of linked multiple scales applies to the collection and interpretation of data. In short, we now need to link observations and modeling at several space scales simultaneously.

All this implies the need for a new approach to Earth and ocean science -- an enduring, integrated approach to the cycle of observation, mathematical and conceptual theory, process studies, data management, and numerical modeling. The primacy of observation is significant; experience shows that without sustained observations of what actually happens, theories, no matter how conceptually or computationally sophisticated, will eventually depart from reality.

There is a growing convergence between research and applications

As argued above, integrated, long-term measurements are now essential to address the fundamental scientific questions regarding the interacting physical, biological, chemical and geological processes in the oceans, and their relationship with the rest of the Earth system. The same is true for the observational requirements of environmental policy and applications. Environmental issues do not respect the boundaries of scientific disciplines. For example, many physical and biological processes leave a chemical signature that can be monitored to separate human-induced and natural changes in the ocean.

Major environmental processes of contemporary concern occur over periods ranging from days to decades, and on a hierarchy of space scales, just as in Earth science. To characterize them, our observations will need to endure as long as the processes themselves. We will need to monitor, document, understand and predict changes in the ocean, on the sea-floor, and near the coasts, over time scales from hours to decades, and space scales from meters to the entire globe.

In short, the needs of research, applications, and policy are coming together for ocean observing.

A mixed research-operational system may be more resilient over the long term

The once sharp distinction between research and operational ocean observing systems is becoming increasingly inapplicable. We believe that the most resilient ocean observing system will have a mixed research and operational character. Observations that must endure for years to accomplish their scientific goals have a greater chance of support if they also serve practical users. Operational systems too stringently designed around today's user needs are less able to evolve to accommodate new scientific knowledge, and thus new types of users. The design flexibility needed to include research goals also encourages continuous technological innovation. It is far better to plan for continuing scientific and technological innovation, as the computer industry has learned to do. Moreover, it is important that there is constructive interaction between observing systems and research. Observations reveal patterns of variation (phenomena) and research determines the causes and consequences of changes. Together, they allow the development of more effective capabilities to detect and predict meaningful changes.

What we must learn to do

Observations pertaining to many disciplines must be integrated and sustained. The observations must be used to improve the design of the observing system. Scientific understanding and observational technology are evolving; new applications are being created; new policy issues are certain to emerge. Thus, the observing system must accommodate change, address numerous scientific and practical objectives simultaneously, and encourage a seamless relationship between research and monitoring. The facilities infrastructure to support the observing system must also be in place.

The observing strategy must preserve the continuity of essential long-term measurements, while responding to changing scientific and practical needs in the short term. In the case of climate, the observing strategy will be designed and evaluated in the light of global numerical models, and must be responsive to policy issues raised by such groups as the Intergovernmental Panel on Climate Change. The strategy must promote broad international participation, not only to share costs and secure adequate geographical coverage, but also to build confidence in the conclusions drawn from the observations. In the case of coastal ecosystems, the observing strategy must enable the development of multidisciplinary systems that incorporate biological and chemical measurements, and must respond to the needs of adaptive management.

The ocean science and operations community cannot avoid dealing with the essential institutional issue of time scales. It must create organizational arrangements and decision processes that can endure for the time needed to accomplish the nation's scientific, policy, and applications goals, during which time political, practical, and scientific priorities will necessarily change.

To achieve all this will take the best efforts of scientists, educators, engineers, administrators, policy-makers, and others around the world for an entire generation or more. But we cannot afford to let the scope and complexity of the ultimate enterprise defeat the will to get started. In this paper, we argue that it is possible to start, today, by shaping current efforts and trends in ocean science. Any sensible strategy starts by building incrementally upon existing programs. In the next section, we argue that the ocean sciences are ready to develop an integrated ocean observing system.

2: Specific examples illustrating the need for long-term, interdisciplinary ocean observations

Ocean-Atmosphere Interactions and Climate

Understanding ocean-atmosphere interactions is essential to understanding climate. The upper 2.5 meters of the ocean contain as much heat as the entire overlying atmospheric column. Variations in the ocean structure and circulation patterns together with the amount of heat the ocean absorbs, stores, and transports dramatically affect how and where the ocean gives back that heat and moisture to the atmosphere. Anomalous regional accumulation of heat in the ocean, as in the eastern tropical Pacific during the last El Nino, has a direct impact on weather and climate over much of the globe. Moreover, there is evidence of a coupling between ocean warming and the 70% decline in the abundance of zooplankton in the eastern North Pacific over the last 20 years. Long-term warming and change in the distribution of warm water at the sea surface is likely also to change the frequency and tracks of tropical storms and precipitation patterns over land.

It is crucial to understand that our ability to forecast the effects and evolution of the 1998 El Nino was greater than for the comparably strong event of 1982-83 because of the El Niño Southern Oscillation (ENSO) observing system and improvements in coupled ocean-atmospheric models. The ENSO array is itself a small integrated system, consisting of NOAA's Tropical Atmosphere Ocean (TAO) array of deep moorings, expendable bathythermographs, and island tide gauges. By integrating these data with radar altimetry data from the TOPEX/Poseidon satellite, researchers were able to provide continuous forecasts of likely consequences for affected areas outside the tropics of what was known to be happening in the tropics.

At present, we can detect an El Nino or a La Nina early in its development, but our climate models cannot predict when the next one will occur. Improvements in observations and modeling are also prerequisite to understanding longer-term climate events such as the Pacific Decadal Oscillation, North Atlantic Oscillation, and Tropical Atlantic Variability, all of which impact both climate and daily weather.

Prior to any human impact, the climate oscillated between warm (today) and cold (ice ages) on the time scale of 1000 to 10,000 years. The basic cause for the transitions between warm and cold climate is generally thought to be variations in the solar energy flux hitting the Earth due to variations in the Earth's orbit. However, the amplified response of the climate system to the changing solar energy flux involves heat and moisture transport by the oceans and atmosphere, changes in the atmospheric carbon dioxide concentration, and changes in the Earth's albedo. Ice-core samples provide evidence for sudden, major changes in global climate on ten- year time scales during interglacial warming periods. Only by understanding natural variations will we be able to distinguish "global warming" from natural climate variability. This is the goal of the international climate variability program (CLIVAR).

There has been much said recently about the fact that US climate models have not played a significant role in assessments by the Intergovernmental Panel on Climate Change. Clearly, the US cannot accept being excluded from a key part of the scientific preparation for international climate negotiations, whose economic and social implications are vast. Initial attention has correctly focused on providing adequate computer resources for climate modeling. This may well assure that US computer models are taken into account in the next climate assessment in a few years. On the other hand, to assure US long-term strength in climate science and policy, a more fundamental effort to develop an integrated infrastructure for observations, data management, and modeling is needed. Sensor intercalibration and data validation is a difficult problem. This must be addressed from the outset. Also, continued analysis of existing data is essential both for continued vitality of the monitoring program and to ensure data quality is maintained at the highest level.

Deep Ocean and Solid Earth Science

Sea-floor spreading and subduction-related arc volcanism expresses the interplay between the magma supplied from the mantle, the large-scale motion of the tectonic plates, and heat loss to the ocean, which is dominated by vigorous hydrothermal circulation. Along mid-ocean ridges and within the Pacific "ring of fire", hydrothermal fluids transport dissolved materials, and the chemical potential energy produced as they rise and mix with seawater sustains diverse communities of chemosynthetic life-forms both on the sea-floor and in subsurface pore spaces. Periodic "diking-eruptive" events may cause very vigorous hydrothermal venting and lead to spectacular microbial blooms. Fault motions and cracking induced by thermal contraction may open new pathways for circulating fluids to enter hot rock, thus temporarily increasing hydrothermal fluxes and changing the local chemistry. It has proven difficult to assemble the full array of equipment necessary to monitor these interrelated systems. Stand-alone experiments are limited by practical considerations to periods that are significantly shorter than the time scales of the volcanic and eruptive events. Sea-floor observatories would enable multi-disciplinary observations at a few key sites on appropriate time scales.

The uneven distribution of observatories between continents and oceans and the northern and southern hemispheres severely restrict our understanding of even the most fundamental of geophysical processes. For example, geochemical evidence strongly favors three major reservoirs for magma erupted at the surface. Two of these reservoirs, one responsible for the magmas erupted at mid-ocean ridges and one the parent of magma erupted at islands, were apparently segregated early in the formation of the planet. Magma generation at subduction zones is a major source of recycling of both solid and fluid constituents of the tectonic plates, and the understanding of how these constituents impact the chemistry of the oceans and the atmosphere is a major component of global mass balance studies. While these reservoirs have been assigned to the upper and lower mantle, current seismic and geochemical evidence precludes the possibility that these parts of the mantle have remained isolated. As the convection models, constrained by seismological, geochemical, and geoid data, become more complex, the importance of higher quality global observations grows. Again, sea-floor observatories are needed.

Ocean Chemistry and the Carbon Cycle

Chemical and biological time series measurements at deep ocean moorings off Bermuda and Hawaii have been underway for the last decade and demonstrate the importance of chemical measurements to understanding the processes that link the atmosphere, upper ocean, and the deep ocean interior. Similar coastal time series are required to document and quantify the linkages between coastal processes and the deep ocean. Even though the deep-sea floor is the most remote territory on Earth, we have learned that carbon and its biochemical energy is rapidly cycled from the atmosphere to the deep ocean on time scales of only months. The sea floor is therefore tightly coupled to the atmosphere and has "seasons", just as the surface of the Earth does, and many deep-ocean processes are driven by the seasons.

On longer time scales, the ocean plays a major role in the sequestration and release of carbon to the atmosphere. The oceans sequester some of the carbon dioxide added to the atmosphere by the combustion of fossil fuels. Carbon dioxide is the most important anthropogenic "greenhouse gas", and predicting its future concentration in the atmosphere is necessary to predicting climate on decadal to centennial time scales. The oceans thus modulate both the anthropogenic effects on climate and the climate itself. A national Carbon Cycle Science Plan (CCSP) to study the global carbon cycle is under development. A key element in this plan is a coordinated observational and modeling effort to measure and predict the uptake of carbon by the oceans over climate-relevant time scales. In particular, the sequestration of carbon in ocean sediments and hydrates extends these time scales well beyond decades into deep time.

Recent improvements in techniques for sampling sedimentary sequences in great detail through the Ocean Drilling Program and measuring ocean tracers and carbon uptake directly, coupled with improvements in the use of ocean general circulation models (OGCMs) in biogeochemical applications, foretell major advances in this area. Indeed, combining ocean carbon observations and modeling with similar atmospheric studies will place important constraints on solving the more difficult terrestrial carbon problem, and thus lead to an improved understanding of the global carbon and climate system.

The Coastal Zone

Observations and predictions of interactions of coastal waters and the atmosphere are as fundamentally important as in the open ocean. The multiplicity of practical issues in the coastal zone provides additional challenges, as well as rich opportunities, for observing systems. Existing and emerging capabilities for measurement and analysis allow the development of observing systems over the next decade to verify predictions of shallow water waves, currents, sea level, and water mass characteristics for continental shelves, shorelines, bays and estuaries. These systems will have numerous applications for infrastructure design (e.g. by taking sedimentation and erosion into account), preparedness (forecasting of waves and storm surges or oil spill trajectories), hazard avoidance (e.g. vessel safety), and environmental and resource management. These systems will be based on strategic observations that continuously feed data-assimilating models.

The wide array of issues confronting society in the coastal zone -- protection of life and property, regional scale weather forecasts, improvement of the scientific knowledge base, environmental protection, fisheries management and adaptation to climate change provide a diverse array of clients for improved coastal observing systems. This places additional demands for multipurpose observing systems, and brings in additional partners from private, state, and local government sectors. As integrated systems serving a diverse clientele, they must go beyond the capability of measurements and forecasts of physical characteristics to address important chemical and biological phenomena, such as concentrations of pollutants and the identity and abundance of organisms. Fortunately, new optical, acoustic, molecular, and information technologies are allowing the development of new sensors and expanding the ability to store and process huge quantities of data to address these needs.

Existing long-term monitoring and research programs would be greatly advanced by integrated observing systems. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) program, for example, was formed in response to the collapse of California's sardine fisheries and has demonstrated over the last 50 years the value to both science and management of such integration of physical and biological measurements. The Chesapeake Bay Monitoring Program has for the last 14 years been measuring physical, chemical and biological characteristics of the bay using conventional approaches in order to track progress in the ambitious effort to restore this ecosystem. It has recognized the need to apply more remote and in situ observations and better integrate observations with research and with water quality and living resource models. The Global Ecosystem Dynamics (GLOBEC) program currently in progress on Georges Bank is assimilating biological distributions and processes into an evolving climate-based circulation model, in order to understand the possible impacts on fisheries of long-term climate shifts. The movement of environmental and natural resource management towards "adaptive management," with its emphasis on learning and dependence both on models and careful monitoring of the outcome of actions, demands greatly improved and integrated coastal observing systems.

Coastal waters must be viewed as part of a spectrum of scales, requiring integration of coastal physical and meteorological observations with those on oceanic and global scales. Perhaps this can be best illustrated by the El Nino phenomenon. Not only do El Nino-influenced storms affect the shoreline, but the

El Nino ocean signature includes a wave response which propagates along coastlines, particularly the Pacific coasts of the Americas. This signal is evident in coastal sea level and ocean surface temperature observations. However, there is a less visible but no less important response in coastal thermocline depth (which deepens), ocean currents, and water properties. Moreover, El Nino-related atmospheric forcing and precipitation patterns also have major influence on coastal waters of the Gulf and Atlantic coasts. All of these changes in physical forces strongly affect biological communities and fisheries. At present there are relatively few corresponding long-term measurements other than of sea level, air and sea surface temperature, and wind velocity to help us understand and predict the consequences of global and basin scale climate variability in the coastal zone.

Coastal observation systems will also serve to integrate relevant information from terrestrial ecosystems, such as changes in land use and land cover and runoff of fresh water, sediments, nutrients and contaminants into coastal waters.

Biological Dimensions

The National Academy of Sciences' marine biodiversity research agenda calls for a fundamental change in the approach by which the abundance, distribution, and variety of life in the oceans is measured and studied. What is needed is an integrated regional-scale research strategy within an environmentally relevant and socially responsible framework. This is now possible because of recent technological and conceptual advances within the ecological, molecular, and oceanographic sciences. Such a decadal-time-scale research program would integrate ecological and oceanographic research spanning a broad range of spatial scales, from local to regional, and over appropriate time scales for distinguishing changes in biodiversity due to effects of human activities from natural phenomena.

Because there are so few long-term interdisciplinary monitoring programs, there is a lack of basic information on trends in chemical and biological structure for most areas of the coastal ocean. This leaves managers and policy makers no basis for evaluating whether present management approaches are effective, and no basis for detecting unexpected events and their causes until they are very obvious and much harder to mitigate. Early detection of trends and unexpected events will require both new observational programs, and additional effort devoted to examining the few historical data that do exist.

New partnerships, which could increase the present very limited interaction between the academic research community and the much larger compliance monitoring community may help in detecting and understanding long-term trends and supporting compliance monitoring. For example, the GLOBEC program will provide to management and regulatory groups a comprehensive and predictive model of physical and biological interactions affecting the early life history and survivability of commercially important fishes on Georges Bank. Likewise, on-line, real-time systems being developed to detect agents of biowarfare and bioterrorism could be modified for use in early detection of harmful algal bloom events and risks from waterborne disease agents.

At the close of the 20th century, marine biologists, and especially marine microbiologists, stand poised to monitor, catalog, and forecast the role of microorganisms in the ocean. Based on molecular signatures, less than 0.1 % of extant microorganisms in the oceans of the world have been isolated in pure culture and characterized. There is no doubt that unknown microorganisms play an important role in nutrient and waste cycling in the oceans. Furthermore, previous beliefs have relied on a presumed endless capacity of the oceans to dilute and isolate anthropogenic wastes, including human pathogens. Now, based on new information that demonstrates long-term survival of human pathogens in ocean water and sediment, that documents upwelling of deep nutrients and colloidal particles including viruses and bacteria, and associates global climate change events with shifts in populations of human pathogens, there is a pressing need to monitor and predict changes in coastal microorganisms. The National Research Council of the National Academy of Sciences, in a recent report entitled *From Monsoons to Microbes,* recommended that environmental monitoring for pathogens be integrated with epidemiological investigations, and that the adequacy of federal and state programs for monitoring waterborne and seafood-borne infectious diseases be evaluated. An integrated ocean observing system would provide the needed platforms for accomplishing these recommendations.

3. The growing readiness of the ocean science community

Integrated Global Ocean Observing --Why Now?

Technological advances during the past decades have made a global ocean observing system possible. These advances include new sensors, new platforms, and new communications hardware and software. Long-term, accurate measurements of ocean salinity and of the air-sea exchanges of heat and moisture are now possible. Surface and subsurface mooring technology provides a new ability to maintain cost-effective observatories in the ocean. Subsurface floats, remotely operated and autonomous underwater vehicles, and acoustic sampling methods have expanded our spatial coverage and permit ready access to observatories for maintenance, data linkage, and time-series sampling. Satellites now observe the sea surface temperature, winds, elevation and color. Color measurements are used to estimate the phytoplankton population of the upper ocean, and new analytical methods may soon allow remote identification of algal types and an estimation of their productivity. Flow-through systems are now available for identifying microbial populations by means of their molecular components. New communications satellites will dramatically accelerate the flow of data from *in situ* ocean sensors, and reduce the cost of collecting those data.

Advances in computers and information technology have made it possible to process immense volumes of data and to create ever more realistic scientific models. The continuing advances in computing power, data management, and networking make possible the fully integrated systems that will have a dramatic impact on our scientific capabilities. Already, computer communications support the new institutional partnerships needed to undertake broad interdisciplinary collaborations and to manage distributed observing systems.

The integration of measurements with numerical models is proceeding. Data assimilation, once the exclusive province of meteorology, is becoming a regular tool in the development of numerical ocean models, and is used already in combination with models to design ocean observing systems. For example, observations of seismic wave propagation, the measurement of geoid height from space, and the collection of geochemical data on Earth's surface are assimilated into global mantle circulation models. The results feed back into requirements for new measurements and to an understanding of the evolution of the planet from deep time. Direct measurements of upper-ocean temperature by acoustic tomography and in situ sensors have been combined with satellite measurements of sea surface altitude in ocean assimilation models. The space data alone cannot be used to infer the change in ocean temperature, whereas the two measurements together tell us more about large-scale ocean circulation. In coastal ecosystems, researchers are beginning real-time, at-sea assimilation of synoptic hydrographic and biological data into circulation models, permitting both calibration of the models and adaptive modification of sampling plans.

The ocean science community has been working in an integrated way for four decades. The international Ocean Drilling Project has been managed by a multi-institutional partnership, the Joint Oceanographic Institutions, since the 1960's. The US has managed its oceanographic research vessels as a single fleet, the University National Oceanographic Laboratory System (UNOLS), since 1972. As the first integrated oceanographic observing system, UNOLS has been the basis of the US ocean science program for nearly three decades, and none of the further extensions discussed here can be implemented without UNOLS. More recently, the National Association of Marine Laboratories has initiated LabNet in order to link environmental observations and information resources among these science sentinels around the nation's coasts.

Internationally coordinated programs initiated in the 1980s, such as the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), the Ridge InterDisciplinary Global Experiments (RIDGE), the study of rifted and convergent plate margins (MARGINS), the Tropical Ocean-Global Atmosphere (TOGA) study, and later biologically focused programs like GLOBEC and Land-Ocean Interaction in the Coastal Zone (LOICZ) have all demonstrated the value of an integrated, multi-disciplinary approach. The ENSO observing system developed for TOGA provides data that are assimilated into numerical models to produce El Nino forecasts. Developed in 1985 for research, this array is becoming an operational system serving science and practical users alike.

Coastal oceanography has reached a point where any researcher or layperson can rapidly access near real-time displays of environmental conditions in regions such as the New York Bight, Chesapeake Bay, the Texas shelf and Monterey Bay and predictions of waves along the beaches of southern California. Integrated physical oceanographic and meteorological studies in such regions as the Louisiana-Texas shelf, the Santa Barbara Channel and Georges Bank have described characteristic patterns of circulation, how these resulted from atmospheric and oceanographic forcing and how they are affected by interannual events. Understanding of the circulation patterns has then been used by biologists in GLOBEC and other studies to explain patterns in larval fish populations. Multidisciplinary studies of upwelling ecosystems along the Pacific coast have related currents and vertical mixing to phytoplankton production and food chain dynamics. Studies involving biologists and biogeochemists, as well as physical oceanographers, have quantified the production and off-shelf transport of carbon in the Mid Atlantic Bight. Currently, such interdisciplinary studies of ecosystem dynamics are being pursued in several shelf regimes under the Coastal Ocean Processes (CoOP) program and through interdisciplinary research on processes leading to harmful algal blooms under the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) program. Integrated scientific approaches have also been applied with great success in estuaries such as the Chesapeake Bay and Columbia River estuary under the Land-Margin Ecosystem Research (LMER) program.

A number of observing systems are in place which can be advanced and from which we can learn. Nearshore erosion patterns and the processes driving them have been monitored by the Corps of Engineers for 15 years at Duck, NC. On the New York Bight shelf a Long-term Ecosystem Observatory (LEO-15) provides intensive spatial and temporal coverage of physical, chemical, biological and geological processes. Other continuously operated observing systems maintained by research institutions include the Ocean Acquisition System for Interdisciplinary Science (OASIS) in Monterey Bay, the Chesapeake Bay Observing System, the Gulf of Maine Observing System, the Texas Automated Buoy System, and the West Florida Coastal Ocean Monitoring and Prediction System. In addition, NOAA operates Physical Oceanographic Real-Time Systems (PORTS) to assist navigation in New York, Tampa Bay, and San Francisco Bay and is installing PORTS for Narragansett and Galveston bays. NOAA also supports a national network of 22 National Estuarine Research Reserve monitoring sites. NOAA and EPA have recently established several pilot sites of a Coastal Intensive Site Network (CISNet), an element of the National Integrated Monitoring initiative. In the last two years, the National Oceanographic Partnership Program has supported the development of regional coastal observing systems, sensors, modeling and data assimilation.

The initial building blocks of a national network of coastal observing systems and the technical ability to advance these systems already exist. It is just a question of how fast this network will develop and how its power will be manifested. The successful efforts in well-defined areas are ready to be carried out in larger regions, and will enable resource managers to make informed decisions regarding the further development of coastal resources. The richly regional nature of the interests and capabilities related to coastal observing systems dictates that the desired national capability be in the form of nested networks to engage regional clients, sponsors and scientists, rather than a "one size fits all," centrally managed system. Nonetheless, core measurements and interconnectivity are required to make the national network greater than the sum of its parts.

A key to designing a successful observing strategy is to articulate the measurement needs that must be fulfilled. The field research done in integrated programs such as those above, and our experience with numerical models, as well as the international examinations of the requirements for a global ocean observation system (GOOS), a coastal observing system (C-GOOS) and a global climate observing system (GCOS), have enabled us to develop an integrated ocean observing system.

Initiatives leading to an integrated ocean observing system

In this section, we survey a few initiatives illustrating the technical state of readiness of the ocean science community to advance towards a more comprehensive and integrated observing system.

Next year, hundreds of ARGO (Array for Real-time Geostrophic Oceanography) profiling floats will be deployed to trace ocean currents and make ocean measurements at depths up to 1000 meters. These profiling floats will be a central element in the Global Ocean Data Assimilation Experiment (GODAE). GODAE will combine in-situ and satellite ocean observations with numerical circulation models in a dynamically consistent estimate of the evolving ocean. The ARGO system and satellite radar-altimetry will be of central importance. GODAE likely will demonstrate the ability to connect ocean observations to both ocean and climate models in a single system. Its prime experimental period is scheduled for 2003-2005, and many ocean scientists expect that GODAE will lead to an operational system.

Time series measurements from the proposed Global Eulerian Observatory (GEO) system of moorings would provide information at high vertical and temporal resolution from the atmospheric boundary layer, down through the ocean mixed layer, to the abyss, on time scales of minutes to years. These measurements can provide reference information for satellite sensing of sea surface height, wind stress, surface chlorophyll, salinity, and other properties, and in turn, help relate observed changes in those surface properties to the underlying water column. Other examples include long-term boundary current monitoring and studies of episodic upwelling of water and nutrients at eastern ocean boundaries, high-latitude air-sea interactions, and oceanic subduction of water masses.

Over the past two years, two permanent sea-floor observatories have been established by US scientists, both using cables to furnish power and communications to sea-floor instruments. HUGO (Hawaii Undersea Geo-Observatory) is located in about 1000 m of water atop the volcanically-active Loihi sea-mount 50 miles from the island of Hawaii. The Hawaii-2 observatory, a permanent sea-floor observatory equipped with a broad-band, three component seismometer, was installed in 5000 m of water about halfway between Hawaii and California in September, 1998.

A global sea-floor observing system is in the advanced planning stage. The proposed Deep Earth Observatories on the Seafloor (DEOS) program, will carry out time series studies using submarine cables and fixed ocean buoys to investigate both global and regional scale processes in the solid earth and overlying water column. There will be two types of seafloor observatories. "Active Process" observatories will be located at mid-ocean ridges where there is complex interplay among tectonic, magmatic, hydrothermal and biological processes and at subduction zones where tectonic and volcanic processes have great destructive potential. "Global Network" observatories would be sited to complete the global coverage necessary to fully image the interior of the Earth. They would provide data on the elastic, thermal, chemical, and magnetic state of the Earth's interior, and a global view of oceanographic variables. With 70% of the Earth's surface under the oceans, global networks will never be complete without seafloor observatories.

For coastal observations, several of the systems discussed, e.g., LEO-15, are already in operation while others can be further improved or initiated. Planning for a U.S. Coastal-Global Ocean Observing System (C-GOOS) has developed consensus among scientists and managers on how this should proceed through a national framework, pilot projects, index sites, and improvements in sensor and modeling technologies. These systems would involve advanced in situ sensors, improved telemetry, underway profiling, satellite imagery, high frequency surface radar systems for the measurement of surface currents, arrays and bottom-mounted instruments teleconnected to shore, visualization technologies, data-assimilating models, and internet access to real-time data and interpretative products for a wide range of users.

The systems already underway and/or proposed probably can be integrated further

Eulerian (or fixed point) observation sites can be used for validation of the sensor systems deployed on freely drifting instruments (where calibration and *in situ* referencing is generally not possible), and the testing of new instrumentation. Such systems can also provide service platforms for other equipment, such as the receivers and transmitters used in acoustic tomography and thermometry. As another example, the DEOS NEPTUNE initiative for a dedicated fiber-optic cabled observatory across the Cascadia Margin and Juan de Fuca plate supports opportunities for other long-term oceanographic observations.

A system design study is needed to ascertain the extent to which the acoustic tomography, GEO, and DEOS projects could share moorings, dedicated cables, and/or ship-deployment and revisit protocols. The siting plans for the moorings in the three systems have a great deal in common; program integration is an attractive possibility. The prima facie case for potential cost-savings through integration is clearly worth investigating. Similarly, it has been suggested that profiling floats carry acoustic receivers for expanding tomographic imaging and fixing the position of the drifters. It is worth noting the Global Ocean Data Assimilation Experiment may offer an arena in which to test the performance of any more integrated observing system.

The most successful descriptions of the coastal environment have relied on a blend of observational techniques. Station observations, drifters and surveys have all been used to provide new information about the weather, circulation patterns, the biology, the geology and the chemistry of the coastal zone. Ongoing research programs such as those sponsored by the Minerals Management Service, the National Science Foundation, the U.S. Army Corps of Engineers and the Office of Naval Research can be extended and coordinated to provide an integrated understanding of the coastal zone. Moorings, underwater observatories like LEO-15, acoustic arrays, and other observing techniques could be integrated into a network of long-term coastal observatories connected by a common information system. For the continental shelf, ongoing research programs that could be built upon include the Coastal Ocean Processes program of the National Science Foundation (an interdisciplinary effort to understand cross-shelf transport on US continental shelves), several other projects aimed at developing prototype time-series observatories, and a nearly decade long time series of observations in the Santa Barbara Channel.

The NDBC network of buoys should provide a platform for additional types of ocean observations. Short-wave radiation and downward looking ADCP have already been successfully employed on a trial basis. Additional physical measurements could include all meteorological variables required to estimate surface heat flux, subsurface temperature, and salinity. The relatively close proximity of NDBC buoys to the coast would make them a natural test bed for time series of biogeochemical variables which are currently not measured routinely. These could include air-sea chemical fluxes, bio-optical properties of water, nutrients etc.

Two of the observational objectives of the NAS agenda for marine biodiversity are related to the goals of an integrated ocean observing system. The first is to improve the understanding of the linkages between local, smaller-scale biodiversity patterns and processes and regional, larger-scale oceanographic patterns and processes. The other is to encourage new technological advances in sampling and sensing instrumentation, experimental techniques, and molecular genetic methods. Although current *in situ* sensors can only make a few relatively superficial biological measurements, developing acoustic, optical, and imaging technologies will soon enable more extensive and detailed observations of biomass, diversity, and functioning of plants and animals. We also note that many biological processes can be monitored with the new generation of chemical sensors, and that new "DNA-on-a-chip" sensor technologies now used in clinical laboratories are on the horizon for ocean observation applications. This new instrumentation will complement the present and ongoing need for hands-on sampling onboard ships. In light of this, the first step for the biological components of an integrated ocean observation strategy is simply to ensure support for long-term research programs.

It will be critical for new observational approaches to build upon existing long-term programs, especially for ocean chemistry and biology.

4: Towards a policy framework for integrated ocean observing

Recognize the interdisciplinary richness of ocean science and its applications

Different parts of the overall ocean research and applications community will be called upon to develop the sub-elements of the overall observing system. Each part of the integrated enterprise will need to proceed at the pace determined by its own scientific and technical readiness, applications development, user demand, and policy requirements. Funding for the separate parts will be provided in the amounts and at the times dictated by these considerations; nonetheless, it is critical to commit to the integration of the larger enterprise.

Given the interdisciplinary richness of ocean science and its applications, the integrated observing system will evolve from more than one starting point. At the present time, we can identify five:

- A physical oceanography and climate system based on current satellite remote sensing and appropriate elements of the ENSO, and ARGO projects, Eulerian arrays, acoustic thermometry, and data management, assimilation and modeling. This would constitute a substantial US contribution to the international Global Ocean Observing System (GOOS), and particularly its climate module, which is the ocean module of the Global Climate Observing System (GCOS).

- Seafloor observatories and other deep ocean measuring techniques, for process studies and to complete a global network. These will contribute to our understanding of the solid earth as well as of the processes occurring in the deep ocean.

- The ocean component of a comprehensive system to monitor the global carbon cycle, consistent with the requirements of the national Carbon Cycle Science Plan. The initial observations of the oceanic carbon dioxide system and related properties, and of the chemical and isotopic tracers used to validate models and to interpret carbon dioxide uptake rates and patterns, will employ existing shipboard sampling and measurement techniques. In the longer term many of these measurements will be transferred to autonomous instrumented buoys and floats.

- An increasingly integrated coastal zone observing system that links regional programs, which engage multiple partners and serve multiple clients. Coastal and global observing systems will have very different technical requirements and modes of operation so separate but closely coordinated design, implementation, and management of open ocean and coastal systems will be necessary.

- Preparations now to develop and incorporate biological sensors on long-term distributed *in situ* systems while continuing satellite remote sensing from space. This means, among other things, determining more precisely which biological parameters we should be measured, developing advanced technologies for remote sensing and *in situ* biological measurements, including biological objectives in observing system design studies, and creating broad governance mechanisms to guide research on the biological dimensions of global change.

Oceanographic research vessels are needed to proceed along all five paths. The UNOLS fleet has been an integrated observing system for decades, and ships and submersible vehicles (manned, ROVs, AUVs) will be part of any integrated ocean observing system of the future. Oceanographic ships and submersibles will deploy and service the distributed elements of the observing system. These elements will be deployed in scientifically informative locations, so the cruises to the deployment sites should provide excellent science if measurements are made along the way. There are many measurements that are made better, or uniquely, onboard ships. This is especially true in the chemical and biological areas.

A complete ocean observing system should also incorporate the capability for rapid response to events that are localized in space and time. Examples of events that are unlikely to be adequately observed by a global Eulerian or Lagrangian observing system include earthquakes, volcanic eruptions, waterborne disease agents, and toxic algal blooms. The ability to characterize such events will require new, low-cost, highly portable sensor systems which can be container shipped on a variety of aircraft and deployed from a ship of opportunity or a small plane. Cooperation and quick decision making at the national and international level will be essential to the success of such a program.

Identify what is standing in the way of integration

There are no institutional means to decide the proper balance of observing elements, so that the various projects and arrays are seen as competing with one another. In a sense, they are getting in each other's way because there are so few means for making the overarching technical decisions.

There is no system integration to make cost effective engineering tradeoffs, there are no technology roadmaps, no technology development programs directed at lowering the cost and improving the performance of the proposed distributed observing systems, there is no standing group tasked with developing an integrated ocean observing strategy at the system design, engineering, and management levels.

There is no clear understanding of how the transition from research to operational observing systems should be managed.

Most importantly, though numerous federal agencies and numerous institutions in the national community have effective ocean observation programs, the network of relationships among agencies, among institutions, and between the agencies and the national ocean community is insufficiently strong to create and manage an integrated ocean observing system. To provide Executive Branch leadership and to establish a policy framework for developing and coordinating ocean observing system activities, a Presidential Decision Directive or Executive Order should be issued. Such a document would advance the national goal of developing a sustained, integrated observing system, promote effective management of the system, support public-private sector partnerships and applications of the resulting system and data, foster development of protocols, and provide a national approach for establishing international relationships.

Stimulate the organizational innovation needed to integrate ocean observations

The NAVY, NSF, NOAA, NASA, EPA and DOE, among other federal agencies, have made and will continue to make important contributions to ocean observations and related activities, through their own laboratories and programs, and by funding programs carried out by the national ocean community. These agency programs will continue to be the foundation of the national effort. What is largely missing is the capability to design, fund, and manage systems and programs involving several agencies, several scientific disciplines, or which are of a mixed research-operational nature. Because of competitive considerations, the national community has found it difficult to agree upon, build, and manage community-wide infrastructure, which would be needed to operate distributed observing systems cooperatively, to manage information from numerous sources, to promote interdisciplinary research, and so on. Thus, organizational innovation is needed, both within the federal government, and within the national ocean community. We recommend that the government and the national ocean community work hand-in-hand to create a set of cooperative and reciprocal relationships to sustain the development of an integrated ocean observing system.

As a first step, it is important to strengthen the interagency coordination that has begun under the auspices of the National Ocean Partnership Program (NOPP) and the National Ocean Research Leadership Council (NORLC). In both FY 1999 and FY 2000, NOPP will fund several integrated ocean observation system projects, and the NORLC is an appropriate forum for program integration at the national level. However, the present NOPP program funding is insufficient overall, and too narrow in scope, since agencies other than the Navy have been slow to participate fully. Strengthened federal agency participation would be needed for NOPP to play a sustained role in the development of integrated ocean observation system.

Work towards a public-private partnership of stakeholders

Given the role and interests of the various government agencies, the academic research community, industry, state governments and non-governmental organizations in a national ocean observing system, there is a fundamental need to foster and enhance communication and cooperation by involving representatives of all stakeholders in a meaningful way. Management approaches should include options for establishing a cohesive public-private partnership which can make effective use of available resources and capture the potential synergies of the various potential participants. A part of this process should focus on the capabilities and strengths of the CORE institutions in research which can contribute to the development, implementation and future upgrades of an ocean observation system. It is also important to consider linkages to the international infrastructure that is emerging to support the needs of the research, operational and commercial user communities. Given the involvement of the CORE institutions in international research programs, they can also assist in international discussions and forums, and support governmental entities in international meetings.

There are numerous international plans for integrated observing systems. For example, beginning in the mid-1980's, international scientific and operational groups began to propose conceptual designs of observing systems that address one or more of the components of the global environment. These plans, misleadingly called systems, include the Global Terrestrial Observing System (GTOS), the Global Climate Observing System (GCOS), and, of particular interest here, the Global Ocean Observing System (GOOS). Developed after extensive international consultation, these efforts signify an international awareness that an integrated, interdisciplinary approach is needed for both research and applications in Earth and ocean science. They are representative of numerous other international efforts to design observing systems for one purpose or another.

Develop and implement observing system funding, planning and management options

Funding and management options for implementation must be considered to budget and execute any plan for]tional ocean observing system. In the near term, the existing NOPP infrastructure should develop options to address the community-wide, integrated management process required to implement this national effort. Over the longer term, the White House, Congress, the relevant federal agencies, and the national ocean community need to reach fundamental agreements on how to work together to integrate the funding, planning, and management of ocean observing systems. Overall implementation approaches and options should be developed at three levels; funding, management and organizational structure. Both budgeting and implementation can be achieved in a phased manner, while addressing the highest priority needs in a logical and affordable approach. The purpose here is to present a range of options for consideration, not to recommend a specific approach at this time. Each of the options has its advantages and disadvantages, and those that represent a possible mechanism for implementation should be more completely developed.

However, the essential elements of the observing system implementation must include:

Participating federal, state, academic, industrial organizations;

A distributed system and knowledge base;

A managed communication system;

An organization for integration;

Policies for standards, protocols, access and network operations;

Policies for quality assurance;

An archive(s);

A mechanism for transitioning from research to operations.

The following discussion provides a framework that addresses these essential management elements.

Funding and management - near term approach

In the near term, the existing NOPP structure provides an opportunity and mechanism to make recommendations to the NORLC on overall program management and implementation. NOPP also provides a mechanism to augment ongoing activities and immediately start key near term initiatives as indicated in Section 5. However, additional multiagency funding must be provided to undertake and accelerate these essential activities and to ensure broad agency commitment to a national ocean observing system. Funding should be allocated to a combination of directed activities and competitively selected, peer reviewed projects which allow for innovative approaches and new technology developments.

Consideration should be given to changing the title of NORLC and Ocean Research Advisory Panel to ensure a necessary longer term view toward operations, as well as research. The legislation that established NOPP should be reviewed to see if any additional changes are warranted, but it currently provides a framework to move forward. In this regard, it is possible to broaden and strength the NOPP further by using it as the basis to establish a strong public-private partnership. This will be addressed under implementation options.

While a phased approach should emphasize national implementation as a high priority, U.S. interests also involve active participation in international programs such as the Global Ocean Observing System. International involvement requires a management framework for funding commitments, coordination and implementation. While various organizational models exist, one that has been highly successful is the Ocean Drilling Program which is jointly funded by the National Science Foundation (NSF) and international partners from Europe and the Pacific Rim, and managed by the Joint Oceanographic Institutions (JOI) as the prime contractor for NSF. Key elements of this approach should include an MOA between a lead U.S. Government agency and the responsible funding agency in a partner(s) nation, a council representing all the partners, an international scientific advisory panel, and a lead organization representing U.S. interests.

Funding and management - long term options

Since the integrated ocean observing system by its very nature will serve a variety of research and operational needs and users, and have a number of components it will in fact be a "system of systems." Consequently, the management and funding structure that is established in the longer term must be flexible, but also provide an umbrella for integration which addresses a variety of purposes. At the same time, individual organizations have missions and functions that must be met without threatening organizational prerogatives. The options below range from establishment of an institutionalized coordinating mechanism to a fully integrated program office.

- Build on the NOPP model using an executive committee, advisory committee and technical working groups to formally coordinate agency planning, funding, program development, and execution. A secretariat or program office is required to manage and support the overall process. A formal interagency memorandum of agreement (MOA) should also be signed among the participating agencies, which specifies membership, functions, actions, roles and responsibilities.

- Single agency funding with a commitment by the Office of Management and Budget and Congress that the funds are for an interagency/national program. Execution of this approach requires an interagency task force or working group, and perhaps a Federal Advisory Committee in order to include potential non-federal user groups. This approach assigns responsibility for leadership, budgeting and control to a single agency, but could restrict the role of the private sector and non-governmental organizations (NGOs). It also puts the program funding at risk as priorities within an agency or in the congress shift with all or the predominant funding residing with a single source.
- Multiple agency funding linked by an interagency MOA, coordinated through a steering committee/interagency working group, with projects funded by each agency...designate lead agencies for specific applications, such as coastal observations, deep ocean, geophysical. Multiple agency funding results in active participation and ownership or "buy-in" by the partner agencies.
- Multiple agency funding linked by an interagency MOA, with oversight by an executive steering committee and funds provided to and managed through an interagency program office. Matrix support for acquisition, operations, facilities, etc are provided by specified agencies. Staffing responsibilities are specified in the MOA, with a host agency designated.

Implementation and operations options

Implementation options are focused on four key functions, technology development, data and information management, applications and operations. The overarching issues of funding, executive level coordination, and system program management are addressed in the options above. These options are not mutually exclusive and each can address any or all of the key functions.

- Establish a National Virtual Center for Ocean Observations. The "Virtual Center" provides overall coordination, but specific responsibilities reside at specified centers of excellence (nodes), which are either discipline or functionally oriented. Nodes would have responsibility for specified observations and/or data management, such as open ocean, geophysical, coastal, etc. and related applications. This is essentially a hub-node concept. Such a "Virtual Center" serves as a clearinghouse linking providers and users of data and information, and maintains the essential communications system. This approach naturally lends itself well to data and information management, where government and academic data centers and centers of data would be linked, with NOAA for example taking the lead through its national data centers. But, it also lends itself to technology and applications development as well.

- Establish a Joint Institute/Center for Ocean Observations which serves as a focal point for technology development and information management. This approach would involve an academic based R&D organization under contract to the government and managed by a CORE type-entity collocated with a government laboratory. The Institute is designed to promote research, development and transition to long-term operations and build expertise in areas of relevance to various users. Research would be conducted by a core of academic and government scientists working together, visiting scientists from industry, academia, and federal laboratories, and graduate and post doc fellows. By building on the strengths and expertise of both academia and government laboratories an organization of this type could develop a clear transition path from research to operations, e.g. from basic research to full operations and maintenance.

- Establish a centrally managed data management, fusion and distribution center similar to the DARPA Center for Seismic Studies, or that operated by the Navy during the Cold War for all- source ASW data against Soviet submarines at sea. Such a facility would collect and distribute data to a broadly-based user community, and provides a focus for applications development and R&D in specific technical areas.

- Develop a nonprofit CORE/JOI-like entity composed of interested oceanographic institutions. This entity will accept grants and contracts from the government and manage the distribution of funds among its member institutions and others working in partnership with government laboratories. It would shift some of the burden of coordination and allocation of tasks from the government to a distributed federation of active research organizations, taking advantage of the research capabilities of academia to develop new and innovative methods. The consortium will increase the long-term stability and credibility of the academic institutions' commitment to this enterprise.

The last option could also provide the lead for expanded NOPP activities by establishing a cohesive public-private partnership to make effective use of available resources and the potential synergies from all stakeholders. A potential model for this organization is the Intelligent Transportation Society of America (ITS America). ITS America was created by the Congress in 1991 through the Department of Transportation to institutionalize a public private partnership to implement programs and guide research and development activities related to the nationwide intelligent transportation system. Utilizing that model and building on the existing NOPP structure and legislation, it could be possible to develop a national ocean observing system organization that brings together stakeholders from federal and state governments, industry, academia and non-governmental organizations. The basic principle of such an organization is that government funding is oriented toward providing a public good or benefit, while leveraging and stimulating private-sector investment and capabilities.

Most of the options presented here are, in fact, not mutually exclusive. There is overlap and the final recommendation should be some combination which best serves the needs of the observing system, the funding agencies and the user communities. In the end the actual management structure must reflect the type of observing system that is designed and all of its components. Clearly, with today's technology a virtual approach that links organizational entities (hub/node concept) is desirable. In this way, there is no need to "build" a large facility and the strengths of individual institutions and laboratories can be maximized. However, even in this approach there must be a centralized program office for management and a well defined "hub" or set of "hubs" to enable the integration of specific types of data and to establish and manage the communications backbone, establish standards and protocols, maintain appropriate archives, and develop guidelines for and management of the network.

There are various funding, planning and management options that should be explored leading to the phased development and implementation of an Integrated Ocean Observing System. Building on NOPP provides a transition from the existing structure to a longer term management and organizational approach and the existing Interagency Working Group within NOPP is well positioned to assist the NORLC to make this transition. However, if any of the above is to happen, there must be a long-term commitment to funding, with the appropriate policy framework that links agency commitments with the administration and congress.

5: Elements of a budget initiative for ocean observations

New investments in integrating infrastructure and programs are needed

We believe that new investments in four areas-system design, technology development, pilot projects, and information management- will increase the interdisciplinary richness, technological agility, and applicability of the nation's current programs in ocean observations. These investments are necessary to make progress towards an integrated ocean observing system, and will help to build the cooperative working relationships necessary to build that system.

System engineering and design

Funds should be included in the FY 2001 budget for the system engineering analysis needed to determine whether and how various present and planned ocean-observing systems might be cost-effectively integrated into a more comprehensive system.

To guide the co-evolution of the observing system and oceanographic fleet over the longer term, it will be necessary to create a permanent system integration and engineering design capability, so as to guide the evolving balance between in-ocean systems, space observations and communications, ship operations and research, and data management. One important function would be to produce and update technology forecasts and roadmaps to guide the thinking of the research and operations communities. System studies are needed to address the research-operations transition itself.

We recommend that planning begin at once for a permanent system analysis organization.

Development of observational technology

The 2001 budget should include new funding for technology development projects specifically focused on lowering the costs of existing instruments and platforms, integrating different observing capabilities, and developing new sensors and observing platforms for future systems. The example of biogeochemistry is illustrative. At present, the measurement of biogeochemical fluxes demands immense ship resources; new sensors and instrument technology might enable more synoptic measurements from distributed observing platforms at a lower cost. More generally, not all the disciplines needed to understand the ocean have arrived at a common level of instrument development. It is only with new sensor development that we can enable consistent synoptic observations and arrive at the truly multidisciplinary understanding of the oceans that is needed.

Pilot Projects

The 2001 budget should include funding for pilot projects demonstrating an integrated approach to ocean observations. It is important to demonstrate on smaller, regional scales that a multidisciplinary systems approach is both practical and scalable to larger systems. Such prototyping will reveal the issues involved in deploying more complete systems, teach researchers how to work across disciplinary boundaries, and build teams that will operate more complete systems of the future. The pilot projects should utilize existing data and results from current observing systems as well as deployment of new systems.

Information management

The effort to integrate an ocean observing system is without value unless the data it collects are assembled, managed, and distributed to its research and practical users in as near real-time as the specific needs demand and as funding allows. At present, existing ocean data resources are highly fragmented, there are few institutionalized arrangements for sharing or merging of the data being collected, and provisions for the assimilation of data into numerical models are informal at best.

We recommend that the 2001 budget contain funding for projects and/or systems to integrate current data resources, synthesize data collection from several sources, and facilitate the use of data in numerical and other models.

6: Concluding remarks

A strategy is needed to provide the multidisciplinary, long-term data needed to advance basic research and applications in ocean science, and to distinguish natural and human-caused environmental change. A strategic linkage between observations, data management, and modeling is needed to make climate predictions and to guide national and international policy concerning greenhouse gas emissions. A strategy is needed to integrate the ongoing and planned observing systems in physical, geological, chemical, and biological oceanography. A strategy is needed to create observing systems of a mixed research-operational character, so that the data collected serve scientific research and applications.

As stated by Members of the United States Congress last year (Reps. Saxton and Weldon), our nation must "...integrate existing and new ocean observing systems into a coherent, single system to address national needs". With few exceptions, our national agenda for ocean observation currently is composed of separate, short-term, focused scientific studies, and long-term monitoring with insufficient interdisciplinary breadth. We have no national, comprehensive, long-term commitment to ocean observations. A serious and dedicated effort must be initiated, in coordination with federal agencies, industry, and the international research community, to develop an integrated ocean observing system, building upon and enhancing the progress of our national programs for oceanographic research and development.

This review of present programs and plans convinces us that the nation is ready to take the first steps toward the implementation of an integrated ocean observing strategy. This integration could lead to significant savings in the short term and would provide information about the oceans of an entirely new order of comprehensiveness.

Media coverage of the 1997-98 El Nino created public awareness that events in the tropical Pacific ocean have a profound impact on our day-to-day lives. Scientists have long appreciated the need to understand and observe the ocean--now the public begins to do so. We believe that this new public understanding can be transformed into support for implementation of an integrated ocean observing strategy to address critical issues of global importance in the twenty-first century.